



Automated Reasoning CICT Program/Intelligent Systems Project

ATAC-PRT Review

Robert Morris, ARC, Program Manager
Ben Smith, JPL, Deputy Program Manager

AR Goal and Objective

- Increase the overall level of intelligence exhibited by spacecraft and other complex systems required to support NASA's missions.
- Support strategic research in automated reasoning to enable the creation of integrated software and hardware systems that reliably make and execute decisions which traditionally have either been made entirely by, or required intervention by, humans.

Motivation



- Future space missions will need to perform complex operations in order to meet minimum mission science objectives within reasonable costs.
 - Precision landing on a hostile environment
 - Accurate instrument placement for sampling or imaging.
 - Remote exploration without earth contact for a week or longer.
- Attempting these operations with ground controllers
 - Introduces long latencies
 - Imposes heavy demands on operations team
 - Is less responsive to the dynamic and uncertain situations these missions will face.
- Automated reasoning technology will help NASA missions by
 - Increasing the amount of science that can be achieved
 - Ensuring safety of spacecraft and surface explorers in hostile and unknown environments
 - Enabling more robust mission operations

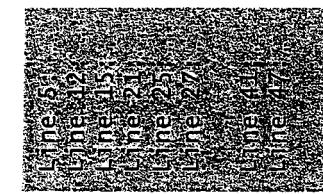
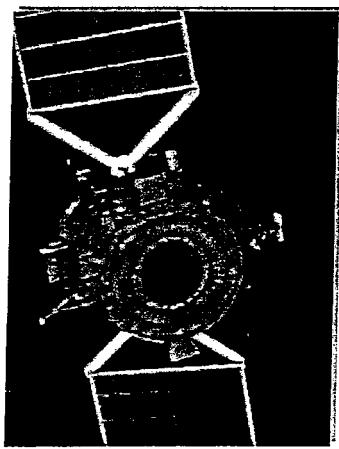
AR Impacts



- Unmanned, deep space exploration using intelligent spacecraft, rovers, and mission operations tools.

- A new generation of automated reasoning capable of operating in dynamic and hazardous environments while maximizing science return to Earth

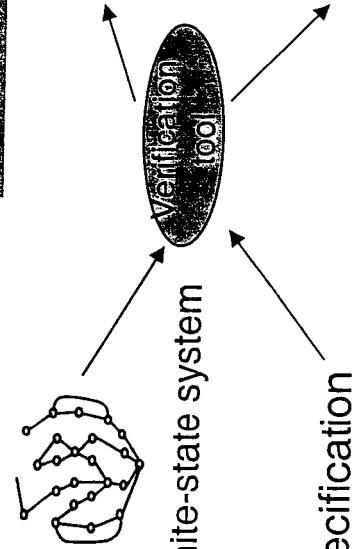
Impact: Increase in science returned from a mission



- Software tools which allow the automated generation and testing of autonomy code for flight software

- Requires the development of formal methods and model-based reasoning techniques to enable automated generation and testing of autonomy software

Impact: Reduction in ground operations staff per mission



Strategic Plan and Metrics



- Support basic research in technology for enabling autonomy in NASA missions
- Demonstrate technologies that support the need to significantly increase the level of autonomy within NASA's future missions
- Support mission infusion efforts in autonomy
- AR Metric:
 - increased degree of autonomy (ratio of machine decisions to human decisions performed during a mission)



- **Intelligent Sensing and Reflexive Behavior**

- Computational approaches to reflexive behavior that improve the ability of autonomous systems to maintain their health while detecting scientifically important objects, events, and situations in its environment.

- **Planning and Execution**

- Large-scale, concurrent planning under uncertainty involving continuous quantities such as time and resources.

- **Model-based Fault Protection**

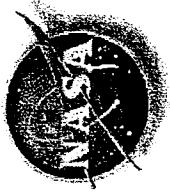
- Diagnosis for both discrete and continuous failures, for discriminating between component failure and environmental influences, and for folding model-based fault management into an autonomous executive control loop.

- **Distributed Autonomy and Architectures**

- Developing computational techniques for optimizing performance across multi-agent systems.

- **Verification and Validation of Autonomy**

- Addressing the complexity in verifying autonomy systems that operate in rich and uncertain environments, and that must adhere to internal correctness constraints involving communication among components, control flow, and resource utilization.



Selected Accomplishments in AR

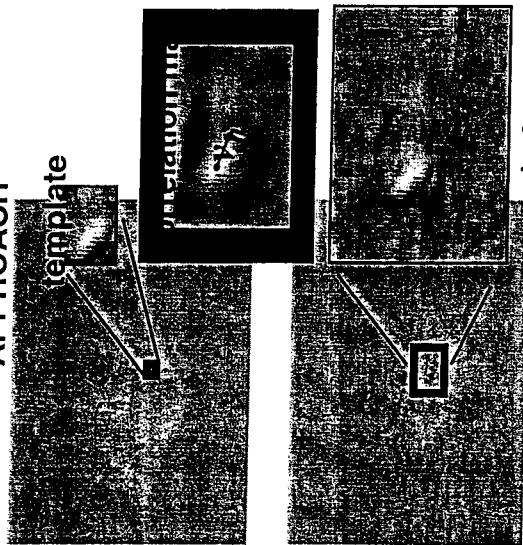
May 20, 2003

Intelligent Sensing and Reflexive Behavior

Descent Image Motion Estimation Subsystem for MER



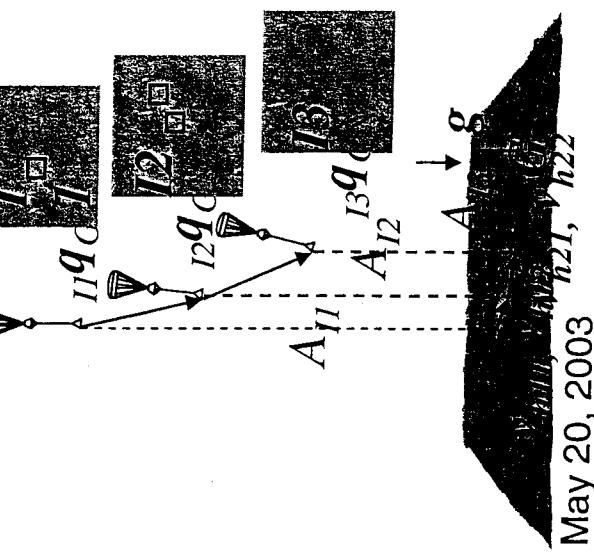
APPROACH



Problem: Steady state winds

during descent could impart a surface relative horizontal velocity to the Mars Exploration Rovers (MER) landing system, threatening lander safety.

Solution: estimate the horizontal velocity of the lander from images taken of the surface during terminal descent.



Approach: DiMES computes horizontal velocity, checks the answer for validity and passes a horizontal velocity correction to the Transverse Impulse Rocket Subsystem (TIRS). TIRS uses the horizontal velocity correction along with measurements of attitude to compute a TIRS rocket firing solution that reduces both RAD rocket and steady state wind induced horizontal velocity.

May 20, 2003

Intelligent Fault Management

NeuroControl for Shuttle Docking

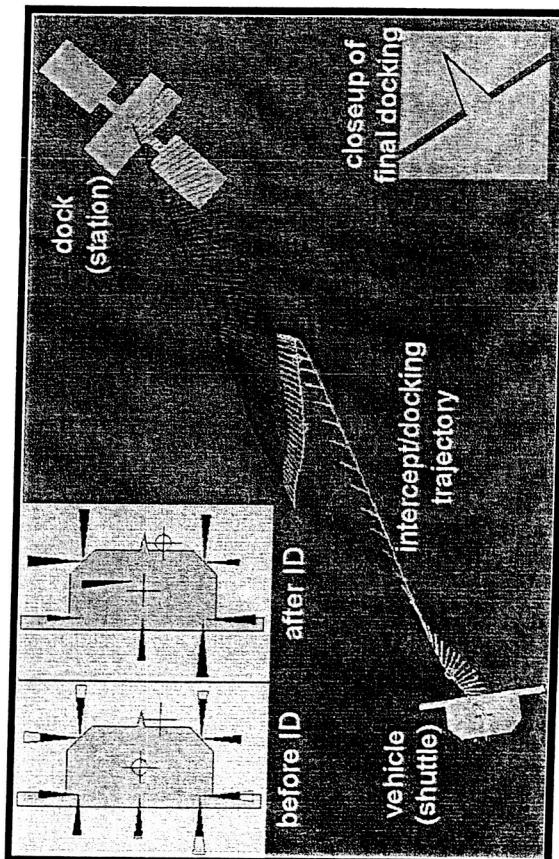


PROBLEM: Docking a spacecraft under manual joystick control can be risky, and is highly dependent on the skill of the pilot. Docking to a spinning target is generally too dangerous to attempt.

OBJECTIVES: Adaptive, intelligent, fault-tolerant controllers that can learn (in real time) changes in vehicle mass properties, thruster strengths and failures, leak thrusts, and other disturbances. This will enable safer, more accurate, and more fuel-efficient control of spacecraft navigation and docking, including safe docking to a moving target.

APPROACH: Adaptive neurocontrol technologies will be used to learn a model of the spacecraft from its operating behavior. Optimal control information communicated to the astronaut through a combination of visual and force-feedback signals. Performance of semi-automated and fully automated control modes will also be tested, allowing "scalable autonomy" as needed by future missions.

PROJECT STATUS: Experiments on ISS under MIT/SPHERES project focus on testing technologies on real-time spacecraft mass property identification using motion sensor information. In preparation, preliminary engineering testing of technologies were conducted using the SPHERES in KC-135 0g flights in Feb 2003.



May 20, 2003

Planning and Execution *MAPGEN for MER*



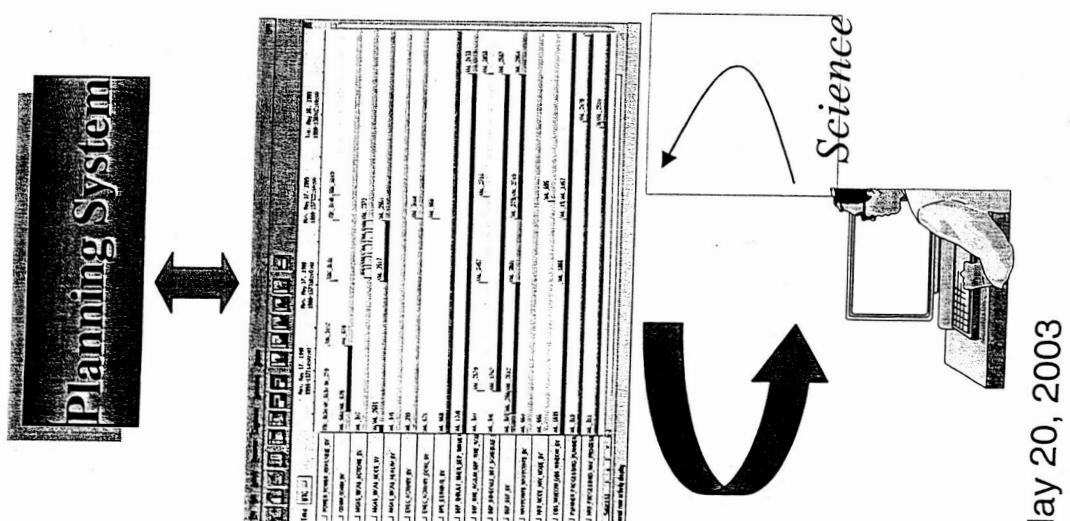
Science is the primary driver of MER and making best use of the rover scientific instruments, within the available resources, is a crucial aspect of the mission.

To address this criticality, the MER project has selected MAPGEN (Mixed-Initiative Activity Plan GENERator) as an activity planning tool.

MAPGEN has the following capabilities:

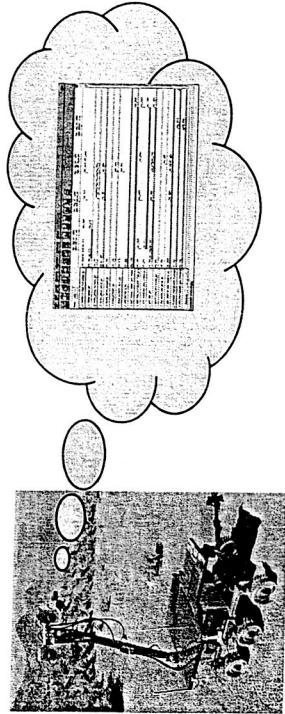
- Automatically generates plans and schedules for science and engineering activities.
 - Hypothesis testing (using what-if analysis on various scenarios).
 - Plan Editing.
 - Resource computation and analysis.
 - Constraint enforcement and maintenance.

MAPGEN combines two existing systems, each with a strong heritage: APGEN the Activity Planning tool from the Jet Propulsion Laboratory and the Europa Planning/Scheduling system from NASA Ames Research Center.

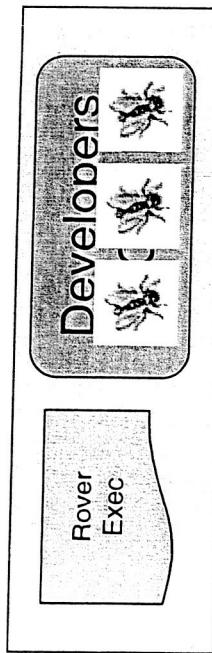


Verification for Autonomy

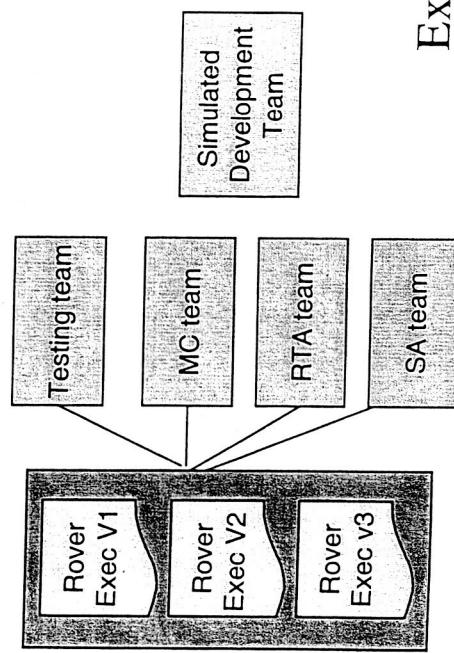
Benchmarking Tools in Verification



Challenge: benchmark the state-of-the art in advanced V&V tools as applied to autonomy software.

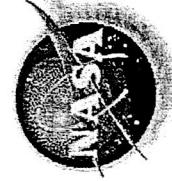


Experimental input: the code for an autonomous rover executive and the log of software defects during its development.



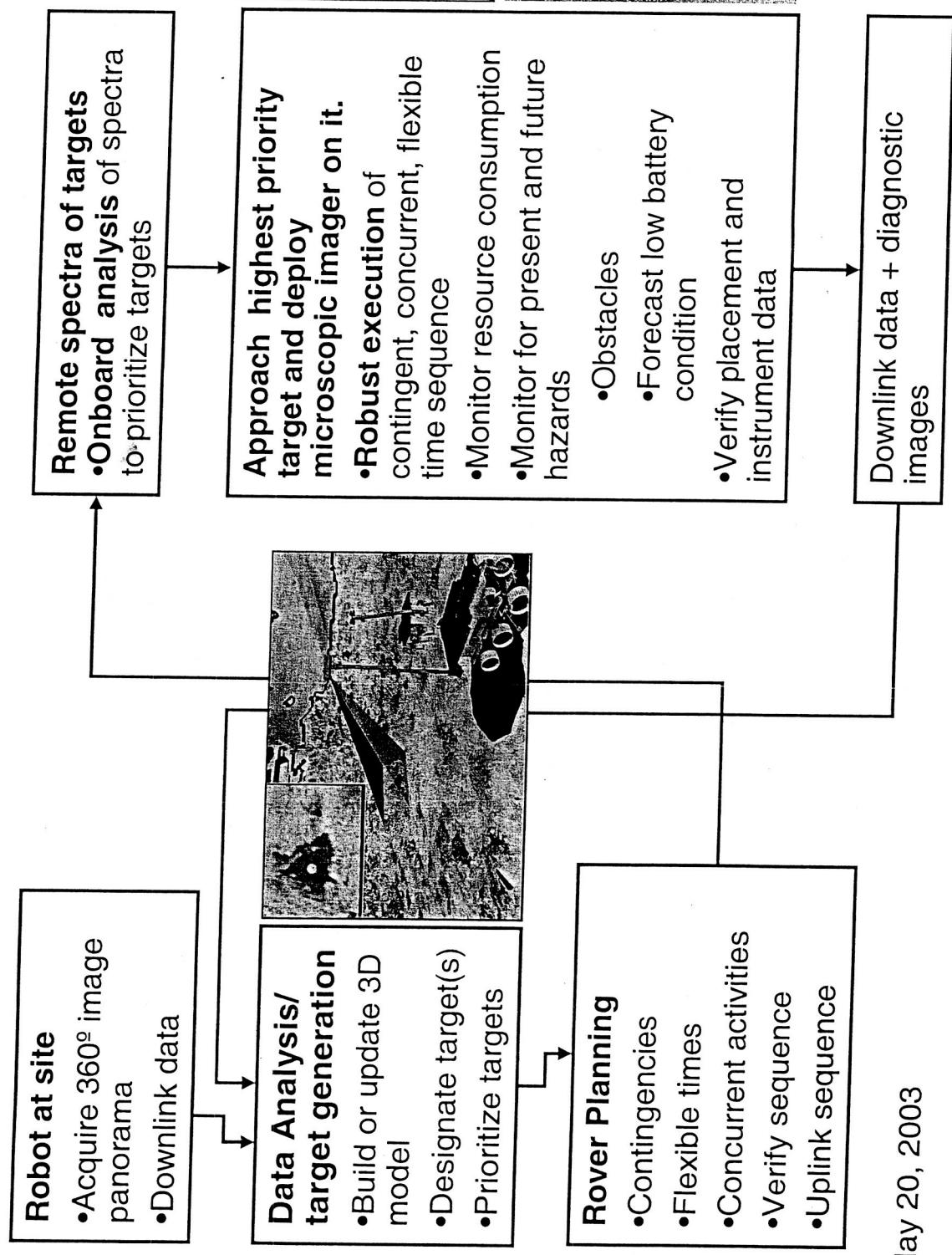
Experimental setup: simulated a development team producing 3 successive versions of the rover software. Experimental subjects were 4 independent V&V teams using individual advanced tools or baseline testing-only group. Simulated development team fixed bugs as V&V teams found defects.

Experimental outcome: 400 hours of data acquired on use of advanced V&V tools. Effectiveness on autonomy software was demonstrated.



Integrated Autonomy Demonstration

Single Cycle instrument Placement



May 20, 2003

Summary



- AR objective: Support strategic research to enable the creation of systems that reliably make and execute decisions traditionally made by humans.
- Autonomy leads to
 - Increased mission assurance: Ability to respond to a wider range of environmental and system health conditions.
 - Improved performance: Increased science return and more efficient operations due to the systems ability to respond to opportunities.
 - Decreased cost: Reduction in mission ops cost and potential decrease in mission development costs.
- AR strategy:
 - Build component autonomy technology
 - Based on 5 key technology areas
 - Demonstrate integrated systems
 - Mission infusion



Backup Slides

May 20, 2003

AR Management

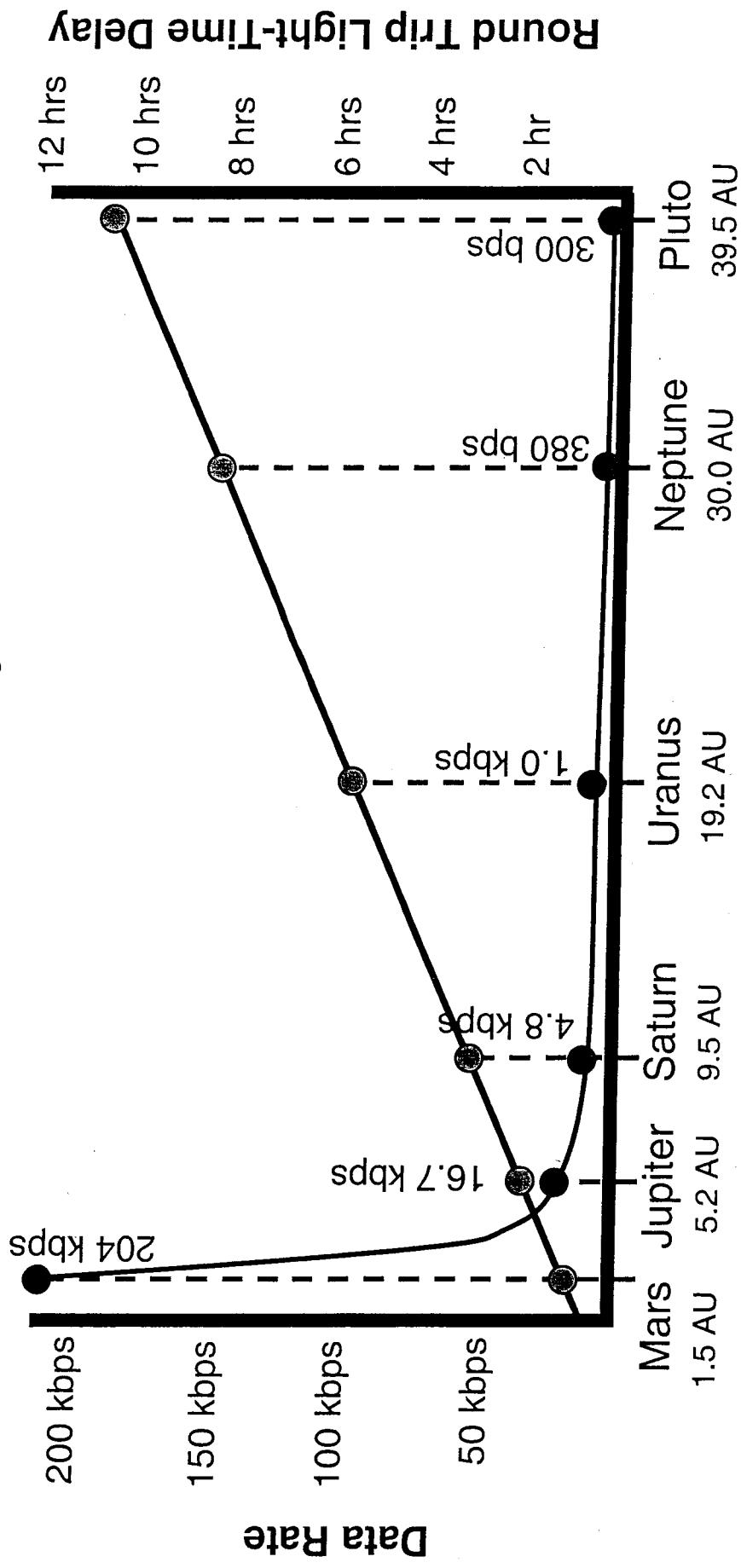


- Collaborations with programs and missions
 - AIST
 - ASTEP
 - MTP
 - MER
 - MSL
 - MIT SPHERES/ ISS
 - EO-1
- Monthly PI Highlights
 - Site Visits
- Annual PI Workshop

Time Delay/Data Rate for Remote Communication

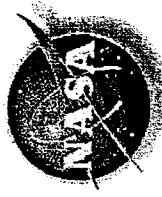


Effect of distance on data rate for X-band RF communication with 5 watts transmitted power from a 2-meter spacecraft antenna into a 70-meter ground antenna



At orbit of Pluto it will take ~10 hours to send a command from Earth and receive acknowledgement!

Complexity Comparisons for Mars Missions



	Sojourner	MER	MSL
Mission Duration	30 days	90 days	1,000 days
Total Traverse	100 m	600 - 1000m	3,000 - 69,000 m
Meters / sol	3 - 10 m	100 m	230 - 450 m
Science Mission	• APXS	• 5 instruments • rock-abrader	• 7 instruments • sub-surface science package (drill, radar) • in-situ sample "lab"

Mission complexity is increasing

Time spent waiting for instructions must decrease
(longer traverses, more science/soil)

Demands on operations teams are increasing
(fast uplink/downlink turnaround, complex missions & science decisions, over longer missions)

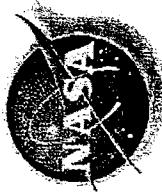
Intelligent Sensing and Reflexive Behavior



TASK	PI/Institution	EMAIL
Onboard scientist for multi-rover scientific exploration	Estlin/JPL	tara.estlin@jpl.nasa.gov
3D super-resolution from multiple images	Cheeseman/ARC	cheesem@ptolemy.arc.nasa.gov
Super-resolved 3D surface models from rover images	Cheeseman/ARC	cheesem@ptolemy.arc.nasa.gov
Autonomous vision-guided safe & precise landing	Matthies/JPL	lhm@robotics.jpl.nasa.gov
Pet Martian Rover	Nourbhakhs/CMU	illah@cs.cmu.edu
Autonomous Rotocraft Scorpion	Patterson-Hine/ARC	Frances.A.Patterson-hine@nasa.gov
Navigator and Effector Control	Kirtchner/NorthEastern Univ.	frank.kirchner@qmd.de
Spacecraft MicroRobot	Pedersen/ARC	pedersen@email.arc.nasa.gov
Neuro Control for Shuttle Docking K9 Platform	Dorais/ARC	Gregory.A.Dorais@nasa.gov
On Board Science Data Analysis	Mah/ARC	Robert.W.Mah@nasa.gov
Probabilistic Prototyping	Bualat/ARC	Maria.G.Bualat@nasa.gov
	Castano/JPL	r.castano@jpl.nasa.gov
	Macready/ARC	wgm@riacs.edu

May 20, 2003

Planning And Execution



Task	PI/Institution	Email
Probabilistic Reasoning for Complex Dynamic Systems	Pfeffer/Harvard	avi@eecs.harvard.edu
Integrated Development Environment for Planning	McGann/ARC	cmcgann@email.arc.nasa.gov
Multi-Resolution Planning in Large Uncertain Environments	Kaelbling/MIT	lpk@ai.mit.edu
Limited Contingency Planning	Smith/ARC	de2smith@email.arc.nasa.gov
On-board Autonomy for Rovers	Washington/ARC	richw@ptolemy.arc.nasa.gov
System Level Autonomy Infusion for MSL	Crawford/ARC	jc@email.arc.nasa.gov
Heuristic Control of Planning and Execution in Metric and Temporal Domains	Kambhampati/Arizona	rao@asu.edu
Integrated Planning and Path Planning	Estlin/JPL	tara.estlin@jpl.nasa.gov

Planning And Execution



Task	PI/Institution	Email
Using Combinatorial Optimization Algorithms to Improve Automated Planning and Scheduling	Smith/JPL	smith@aig.jpl.nasa.gov
Stochastic Anytime Search with Applications in Autonomous Planning and Scheduling	Wah/Illinois	b-wah@uiuc.edu
IDEA	Muscettola/ARC	mus@email.arc.nasa.gov
SOFIA Scheduling	Frank/ARC	frank@email.arc.nasa.gov
MER Rover Sequence Generation	Rajan/ARC	krajan@email.arc.nasa.gov
Rover Autonomy Architecture	Nesnas/JPL	nesnas@jpl.nasa.gov
Integrated Planning and Execution	Fisher/JPL	forest.fisher@jpl.nasa.gov
Hybrid Dynamic Constraint Satisfaction Problems: New Approaches and Applications	Boddy/Adventum Labs	mark.boddy@adventumlabs.org
Action Theories and the Design of Intelligent Systems	Watson/Texas Tech	dave.watson@jhuapl.edu
Constraint-based Planning	Smith/ARC	de2smith@ptolemy.arc.nasa.gov

May 20, 2003

Model-based Fault Protection



Task	PI/Institution	Email
Hybrid Discrete/Continuous System for Health Management and Control	Williams/MIT	williams@mit.edu
Robust Methods for Autonomous Fault Adaptive Control of Complex Systems	Biswas/Vanderbilt	biswas@vuse.vanderbilt.edu
Hybrid Diagnosis of Advanced Life Support	Dearden/ARC	dearden@ptolemy.arc.nasa.gov
Enhancing L2	Narashimham/ARC	sriram@email.arc.nasa.gov
Closed-loop Control and Fault Protection of the MMM Interferometry Testbed Using IDEA	Lockhart/JPL	mus@email.arc.nasa.gov

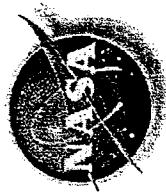
May 20, 2003

Distributed Autonomy and Architectures



Task	PI/Institution	Email
Heterogeneous Multi-rover Coordination for Planetary Exploration	Simmons/CMU	reids@cs.cmu.edu
Continual Coherent Team Planning	Barrett/JPL	anthony.barrett@jpl.nasa.gov
Team Sequencing and Execution	Barrett/JPL	anthony.barrett@jpl.nasa.gov
Artificial Collective Intelligence (COINS)	Wolpert/ARC	dhw@ptolemy.arc.nasa.gov

Autonomy V&V



Task	PI/Institution	Email
Program Synthesis of Verifiably Correct State Estimation Programs	Lowry/ARC	<u>Michael.R.Lowry@nasa.gov</u>
Intelligent Specification-Centered Test Case Generation Review Identifier	Heimdahl/Minnesota	<u>heimdahl@cs.umn.edu</u>
Analytic V&V	Lowry-Brat/ARC	<u>Michael.R.Lowry@nasa.gov</u>
AutoBayes	Lowry-Fischer/ARC	<u>Michael.R.Lowry@nasa.gov</u>
V&V of Autonomous Systems	Lowry/ARC	<u>Michael.R.Lowry@nasa.gov</u>

May 20, 2003

Selected Papers in AR



Topic	Task
Bayesian Super-Resolved Surface Reconstruction From Images Authors: V.N. Smelyanskiy, P. Cheeseman, D.A. Maluf & R.D. Morris	Super-Resolved 3D Surface Models from Rover Images (PI: Cheeseman)
A Layered Architecture For Coordination of Mobile Robots Authors: R. Simmons, T. Smith, M. B. Dias, D. Goldberg, D. Hershberger, A. Stentz & R. Zlot	Heterogeneous Multi-rover Coordination for Planetary Exploration (PI: Simmons)
Vision-based Autonomous Landing of an Unmanned Aerial Vehicle Authors: Srikanth Saripalli, James F. Montgomery, & Gaurav S. Sukhatme	Autonomous Vision Guided Safe and Precise Landing (PI: Montgomery)
Planning Under Continuous Time and Resource Uncertainty: A Challenge for AI Authors: John Bresina, Richard Dearden, Nicolas Meuleau, Sailesh Ramakrishnan, David Smith and Rich Washington	Limited Contingency Planning for Concurrent Activities (PI: Smith)
Factored Particles for Scalable Monitoring Authors: Brenda Ng, Leonid Peshkin, & Avi Pfeffer	Probabilistic Reasoning for Complex Dynamic Systems (PI: Pfeffer)
Automatic Synthesis of Statistical Data Analysis Programs Authors: Bernd Fischer	Amphion/Meta-Amphion: High Assurance Program Synthesis Systems (PI: Lowry)
Mode Estimation of Model-based Programs: Monitoring Systems with Complex Behavior Authors: Brian C. Williams, Seung Chung, and Vineet Gupta	A Hybrid Discrete/Continuous System for Health Management and Control (PI: Williams)
Reinforcement Learning in Distributed Domains: Beyond Team Games Authors: David H. Wolpert, Joseph Sill, and Kagan Turner May 20, 2003	Artificial Collective Intelligence (PI: Wolpert)

Selected Papers AR (2)



Paper	Task
Sapa: A Domain-Independent Heuristic Metric Temporal Planner Authors: Minh B. Do & Subbarao Kambhampati	Heuristic Control of Planning and Execution in Metric/Temporal Domains (PI: Kambhampati)
Livingstone and the Remote Agent Experiment Authors: Richard Dearden, James Kurien, and Peter Robinson	Hybrid Diagnosis of Advanced Life Support (PI: Dearden)
"Initial results from vision-based control of the Ames Marsokhod rover," <i>IEEE Int'l Conf on Intelligent Robots and Systems</i> , pp. 1377-1382, France, 1997 Authors: D. Wettergreen, H. Thomas and M. Buatat.	Navigator and Effector Control (PI: Pedersen)
I.A. Nesnas, M. W. Maimone, H. Das, "Autonomous Vision-Based Manipulation from a Rover Platform," <i>IEEE Int'l Symp. on Computational Intelligence in Robotics and Automation</i> , pp. 351-356, Nov 1999, California.	Navigator and Effector Control (PI: Pedersen)
A. Barrett, G. Rabideau, T. Estlin, S. Chien, "Coordinated Continual Planning Methods for Cooperating Rovers," <i>Proceedings of the IEEE Aerospace Conference</i> (IAC-2001), Big Sky, MT, March 2001.	Onboard Traverse Science Data Analysis (PI: Castaño)
T. Estlin, R. Volpe, I.A.D. Nesnas, D. Mutz, F. Fisher, B. Engelhardt, S. Chien, "Decision-Making in a Robotic Architecture for Autonomy." <i>Proceedings of 6th International Symposium on Artificial Intelligence, Robotics, and Automation in Space (i-SAIRAS)</i> , Montreal Canada, June 18-21 2001.	Rover Autonomy (PI: Estlin)
Nearly Deterministic Abstractions of Markov Decision Processes Authors: Terran Lane and Leslie Pack Kaelbling	Multi-Resolution Planning in Large Uncertain Environments (PI: Kaelbling)

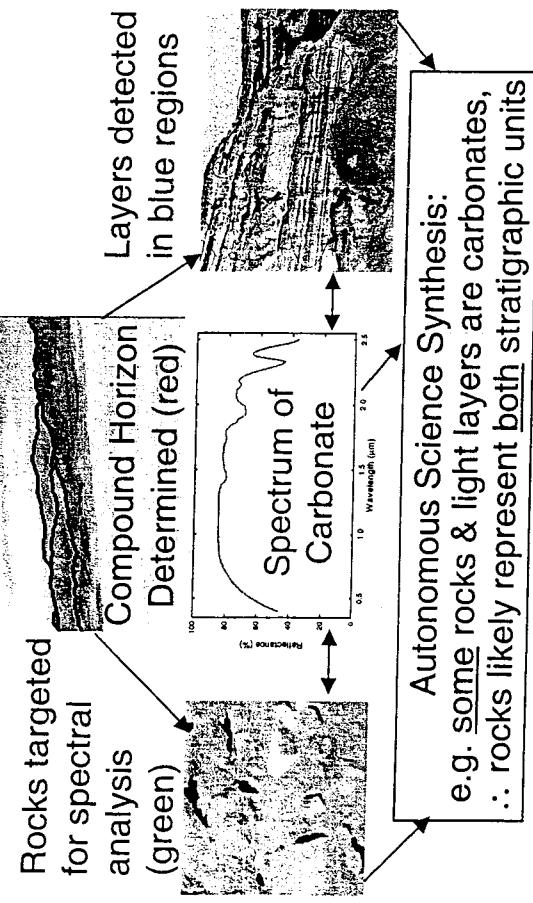
May 20, 2003

Essential Autonomous Science Inference



Objectives

Develop fast autonomous, on-board image and spectral analyses system enabling science decisions to be made on-board future Mars rover missions.



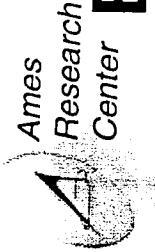
Task Manager: Ted Roush, NASA Ames Research Center, Planetary Systems Branch, 650 604 3526, troush@mail.arc.nasa.gov

Participating Organizations:

San Jose State University Foundation (Paul Gazis)
QSS, Inc. (Liam Pedersen)
Raytheon, Inc. (Chung Park, Mark Shipman)
Carnegie Mellon Univ. (J. Ramsey, C. Glymour)
Bay Area Environmental Res. Inst. (R. Hogan)

URL: TBD

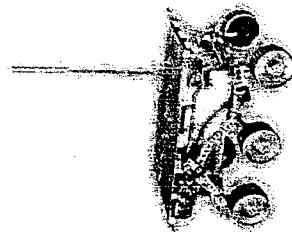
Product Schedule & Funds				
	FY01	FY02	FY03	FY04
Port to CLARAty				
Bayes Classifier/Mapper				
Physical Properties				
NN Analyses				
Field Tests				
Funds	90K	240K	240K	90K



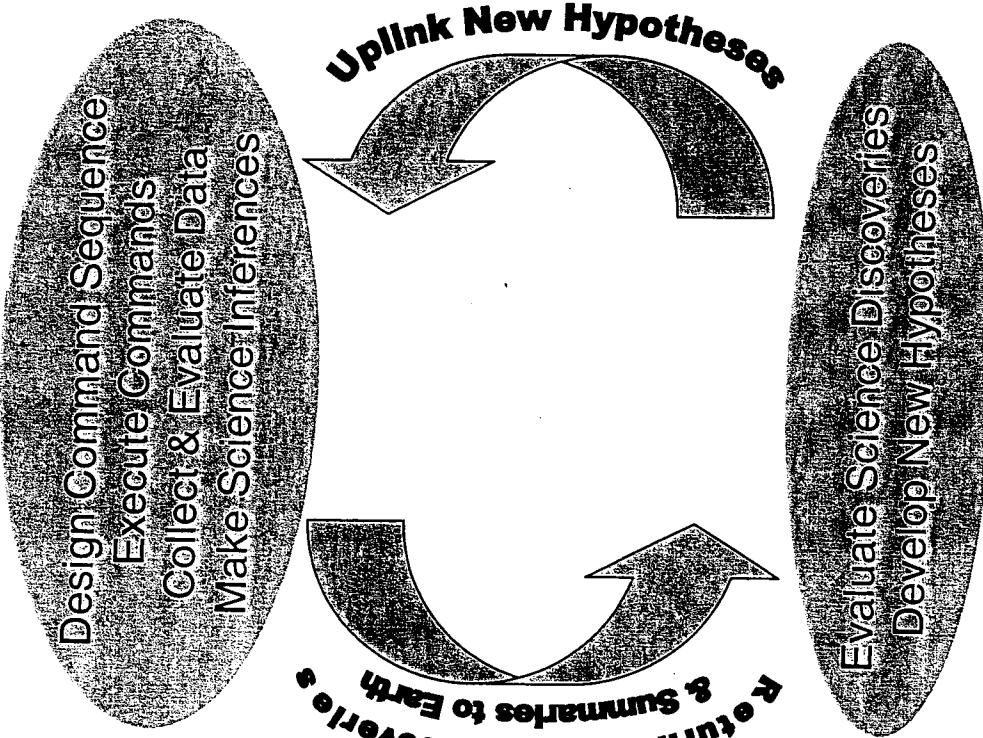
Regional Mobility and Subsurface Access Tasks

Essential Autonomous Science Inference

Historical Spacecraft Mission



Science-Enabled Spacecraft Mission



Execute Commands
Collect Data

Evaluate Data
Make Science Inferences
Design Command Sequence

Return Data to Earth

Uplink Commands



Essential Autonomous Science Inference

Science Autonomy Provides

- Collection of quality science data
 - affected - data collection strategy
 - instrument design provides sensor-rover interface
 - sequence planning and execution
 - unaffected - data compression or return
- On-board science evaluation w/ full fidelity data
 - affected - original data may not be returned
 - data compression
 - data prioritization
- unaffected - future rover activities
 - ability to react to novel data
- Inference of science on-board
 - affected
 - original data summarized
 - original data may not be returned
 - ability to react to novel data
 - future rover activities altered
 - unaffected



Regional Mobility and Subsurface Access Tasks



Essential Autonomous Science Inference Teaming:

Raytheon -

- Chung Park - responsible for implementing spectral algorithm under CLARAty
- Mark Shipman- responsible for implementing imaging algorithms under CLARAty
- San Jose State University
 - Paul Gazis - responsible for providing original code, documentation, and oversight of existing spectral algorithms
 - QSS, Inc.
 - Liam Pedersen - provide original code and expertise in Bayes net implementation
 - Carnegie Mellon Univ. (FY03)
 - Joe Ramsey & Clark Glymour - provide Bayes net carbonate classifier
- Bay Area Environmental Research Institute
 - Robert Hogan - provide Neural Network analysis of IR data
 - JPL - Issa Nesnas, Meemong Lee
 - ARC - Greg Pisanich



Essential Autonomous Science Inference

Milestones

FY02

Level 1:

- 1) Port existing spectral algorithm to CLARAty (15 May 2002)
- 2) Port existing image algorithms to CLARAty (1 September 2002)

Level 2:

- 1) Test algorithms in simulations with various operating systems
- 2) Use image analysis in K9 demo

FY03

Level 1:

- 1) Port Bayes net spectral algorithms to CLARAty
- 2) Port new image algorithms to CLARAty
- 3) Remove VISTA reliance of imaging algorithms

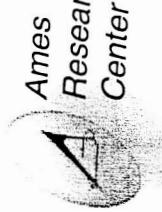
Level 2:

- 1) Test algorithms in simulations with various operating systems
- 2) Test algorithms in field trials

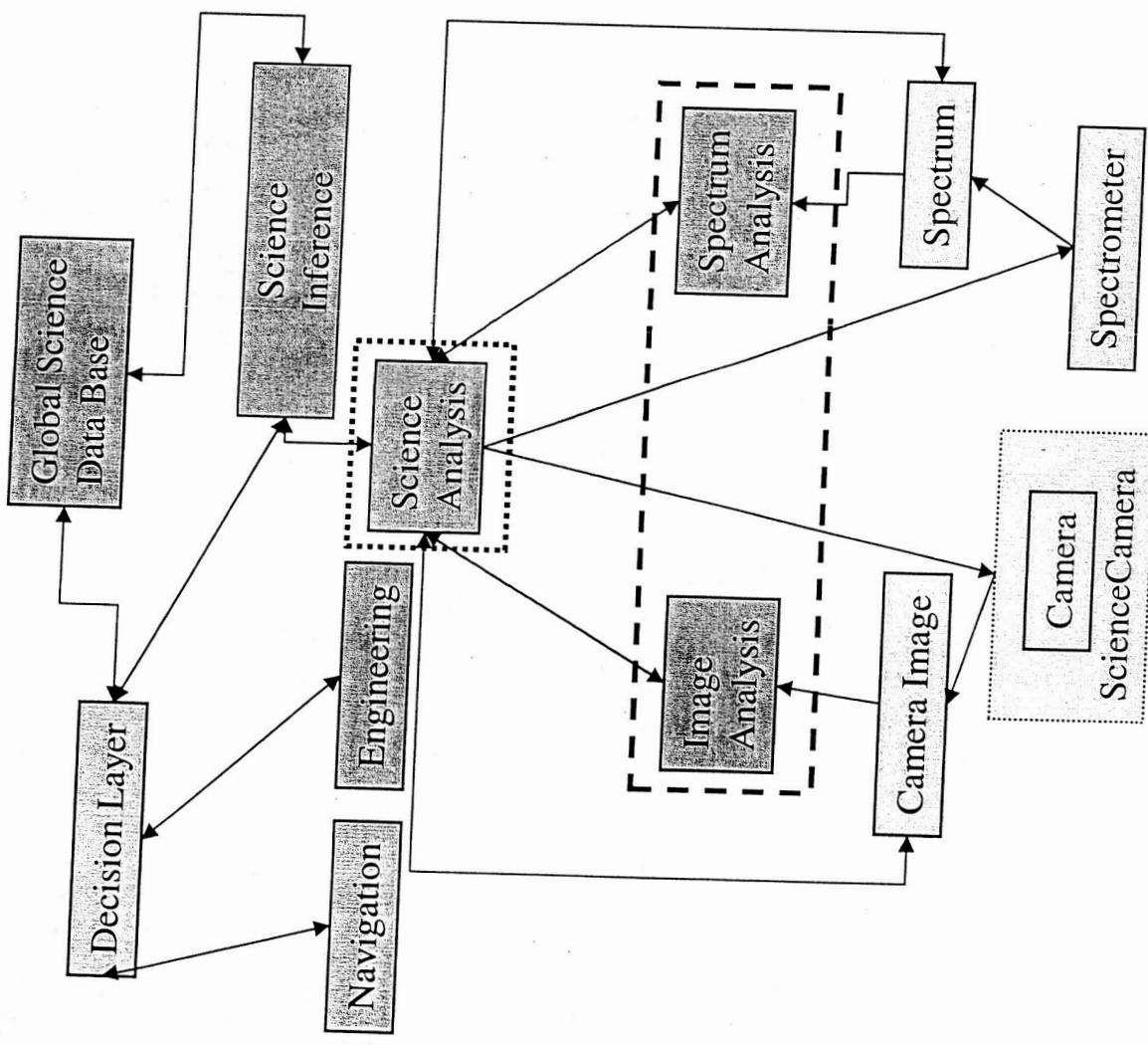
FY04

Level 1:

- 1) Revise and finalize spectral and image algorithms in CLARAty
- 2) Test algorithms in simulations with various operating systems



Essential Autonomous Science Inference



Beginning of FY02 CLARAty did not contain science analysis or science instruments

Jan. 2002 - Began discussion of CLARAty Science Instruments (Issa Nesnas & Meemong Lee)

Apr. 2002 - Delivered spectrum classes to CLARAty

June 2002 - Delivered carbonate identifier class to CLARA^Y (Level 1)

Aug. 2002 - Delivered VISTA
reliant image analysis algorithms
to CLARAty (Level 1)

Essential Autonomous Science Inference

Objective: Evaluate sensor data for science content

Reason: Reduced science data volume allows more science to be measured. Science content can be used for data transmission prioritization

Example

- Identify carbonate rocks
- Find rocks \geq spectrometer FOV
- flag images w/ greatest number
- Point spectrometer at targets
- Evaluate spectral data
- correct instrumental artifact (IA)
- eliminate telluric atmosphere regions (TA)
- flag spectra indicating carbonate (C)
- Prioritize Data Return
- carbonate rock images & spectra
- non-carbonate rock images & spectra
- non-rock images



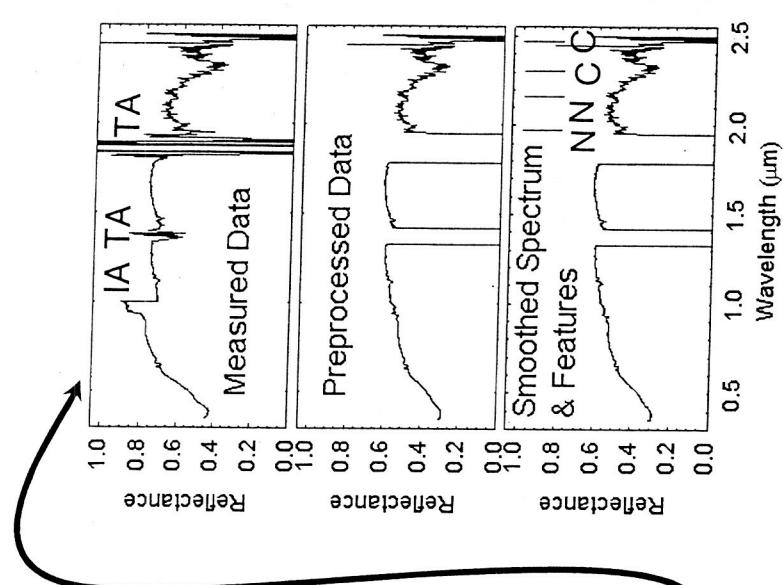
No rocks above fill
the spectrometer FOV

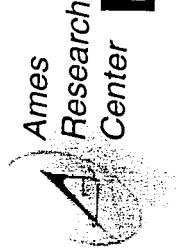


Potential spectrometer targets

O = Spectrometer Field of View (FOV)

Carbonate identifier built & tested
 $P(Auto=C | Field=C) = 69\% (9/13)$
 $P(Auto=C | Remote=C) = 80\% (9/11)$
 $P(Auto=C | Field=NC) = 0\% (0/8)$

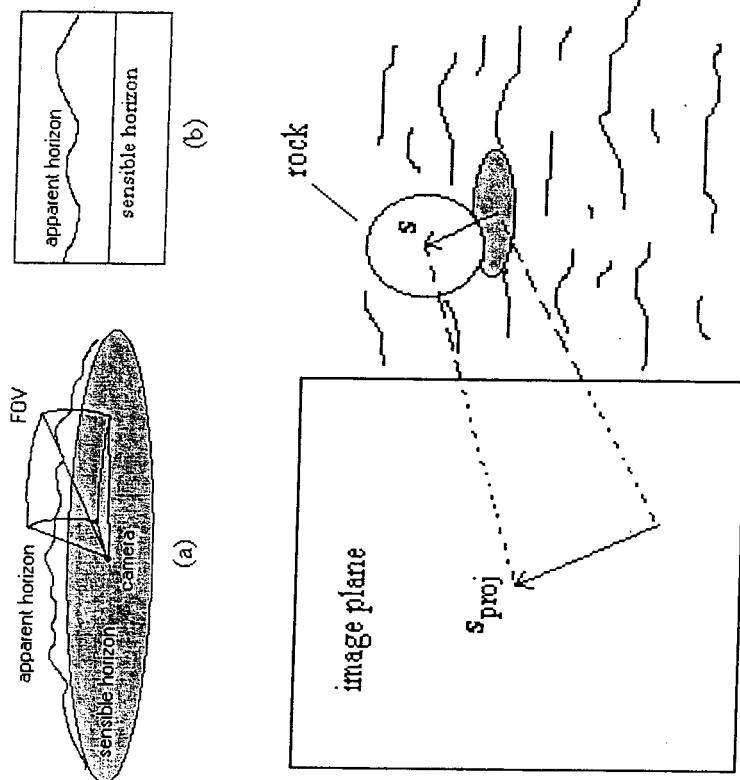




Essential Autonomous Science Inference

- Sky/Horizon
 - Detect color/intensity edges w/in feasible region.
 - Search for edges conforming to expected horizon shape.
 - Rank candidate horizons based on continuity metrics
- Solid Object (Rocks)
 - Use camera pointing & time of day to estimate object/shadow relative positions
 - Object/shadow boundary → object's location & size
 - Spectrometer's FOV <object's size?
- Linear Layers
 - Detect color/intensity edges
 - Search for regions of preferred orientation w/in a given window size
 - Identify regions of dominant edge orientation
 - Record locations & relative amount as percentage & return binary image of these.

Autonomous Image Analyses Algorithms



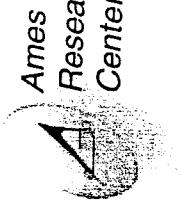


Regional Mobility and Subsurface Access Tasks

Essential Autonomous Science Inference

Significant Events FY 2002

- 1) Dec. 2001 - Funding arrived, project initiated w/ hiring of Chung Park
- 2) Jan. 2002 - Began discussion of CLARAty Science Instruments (Issa Nesnas & Meemong Lee)
- 3) Apr. 2002 - Delivered spectrum classes to CLARAty, hiring of Mark Shipman
- 4) June 2002 - Delivered carbonate identifier class to CLARAty (Level 1 milestone achieved)
- 5) Aug. 2002 - Delivered VISTA reliant image analysis algorithms to CLARAty (Level 1 milestone achieved)
- 6) Sept. 2002 - Discussed incorporation into CLARAty of Bayes net carbonate identifier with J. Ramsey and C. Glymour (CMU) and presented paper at Mars Exploration Workshop in Catania Italy



Regional Mobility and Subsurface Access Tasks

Essential Autonomous Science Inference



Future Plans - FY 2003

- 1) Test existing carbonate identifier using VxWorks (Level 1)
- 2) Deliver image analysis documentation (Level 2)
- 3) Remove VISTA reliance of image analysis algorithms (Level 1)
- 4) Incorporate Bayes net carbonate identifier of Ramsey & Glymour and Bayes net approach of Pedersen (Level 1)
- 5) Incorporate additional image analysis algorithms that recognize scale-invariant morphological features of interest to geology & biology (Level 1)
- 6) Document and test new algorithms with existing data using various operating systems (Level 2)
- 7) Initiate evaluation of science inference using simulations (Level 2)
- 8) Finalize evaluation of SOM's for clustering and classification of thermal infrared spectral data (Level 2)



Regional Mobility and Subsurface Access Tasks

Essential Autonomous Science Inference

Publications/Presentations - FY 2002

- 1) SOM Classification of Martian TES data, R. Hogan and T. Roush, Lunar Planet. Sci. Conf., Abs. #1693, Lunar Planetary Inst., Houston, Texas, 2002
- 2) Automated Remote Sensing with Near Infrared Reflectance Spectra: Carbonate Identification, J. Ramsey, P. Gazis, T. Roush, P. Sprites, C. Glymour, Data Mining and Knowledge Discovery, 6, 277-293, 2002.
- 3) Robotic Exploration, The Role of Science Autonomy, Presented at Workshop on Exploring Mars and Its Earth Analogs, Catania, Sicily, Italy, 23 September 2002
- 4) The Role of Science Autonomy in Robotic Exploration, Invited Lecture, Dipartimento di Fisica, Università Delgi Studi di Lecce, Lecce, Italy, 27 September 2002

